AD-A131 994 EFFECT OF UNCONFINED LOADING ON THE UNFROZEN WATER CONTENT OF MANCHESTER SILT(U) COLD REGIONS RESEARCH AND ENGINEERING LAB HANOVER NH J L OLIPHANT ET AL. JUN 83 1/1

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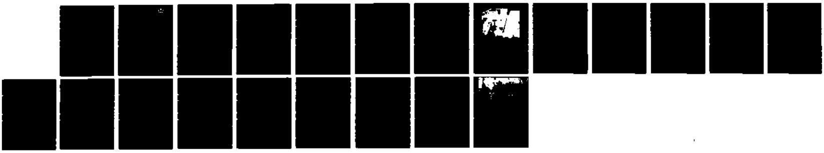

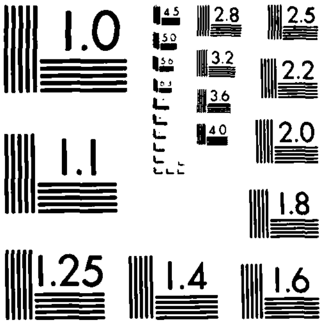

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Special Report 83-18

June 1983

US Army Corps of Engineers
Cold Regions Research & Engineering Laboratory

Effect of unconfined loading on the unfrozen water content of Manchester silt

J.L. Oliphant, A.R. Tice and R. Berg

Prepared for
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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER Special Report 83-18	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) EFFECT OF UNCONFINED LOADING ON THE UNFROZEN WATER CONTENT OF MANCHESTER SILT		5. TYPE OF REPORT & PERIOD COVERED
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) J.L. Oliphant, A.R. Tice and R. Berg		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS U.S. Army Cold Regions Research and Engineering Laboratory Hanover, New Hampshire 03755		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS DA Project 4A161102AT24, Task A, Work Unit 002
11. CONTROLLING OFFICE NAME AND ADDRESS Office of the Chief of Engineers Washington, D.C. 20314		12. REPORT DATE June 1983
		13. NUMBER OF PAGES 19
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Frozen soils
Silts
Soils

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Frozen samples of a Manchester silt having various total water contents were subjected to several surcharge loads, and the unfrozen water content was measured with NMR as the temperature was gradually raised. The surcharge pressure had a greater effect on the unfrozen water content than had been predicted using the Clausius-Clapeyron equation. This effect was explained by considering the loaded samples as nonequilibrium systems in which the surcharge pressures were concentrated in the ice phase.

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PREFACE

This report was prepared by Joseph L. Oliphant, Research Physical Scientist, Allen R. Tice, Physical Science Technician, both of the Earth Sciences Branch, Research Division, and Richard L. Berg, Research Civil Engineer, Geotechnical Research Branch, Experimental Engineering Division, U.S. Army Cold Regions Research and Engineering Laboratory. The project was funded under DA Project 4A161102AT24, *Research in Snow, Ice and Frozen Ground,* Task A, *Properties of Cold Regions Materials,* Work Unit 002, *Physical Properties of Frozen Ground.* Ellen Foley, Physical Science Technician, assisted in carrying out the experiments. The report was technically reviewed by Edwin Chamberlain and Dr. Harlan McKim of CRREL.

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EFFECT OF UNCONFINED LOADING ON THE UNFROZEN WATER CONTENT OF MANCHESTER SILT

J.L. Oliphant, A.R. Tice and R. Berg

INTRODUCTION

One variable that is basic to understanding the frost susceptibility and strength characteristics of a partially frozen soil is the unfrozen water content W_u. The unfrozen water content has been measured directly using calorimetry (Williams 1963, Anderson 1966) and nuclear magnetic resonance (NMR) (Tice et al. 1978). Thermodynamic considerations have made it possible to estimate W_u from soil moisture characteristic curves (Williams 1964, Koopmans and Miller 1966) and from other data relating the activity of the soil water to the water content (Low et al. 1968).

The effect of overburden pressure, or surcharge pressure, on the unfrozen water content has also been predicted using thermodynamic arguments (Edlefson and Anderson 1943, Williams 1964, Low et al. 1968). However, direct measurements of the effect of pressure on unfrozen water content are few. A small amount of data for which the pressure effect is significant has been reported (Tsytovitch 1959). Other experiments that show migration of ice in the soil from areas of high pressure to areas of low pressure (Vialov 1959) also demonstrate a significant pressure effect.

In this study the unfrozen water content of a silt from Manchester, New Hampshire, was determined as a function of total water content, temperature and surcharge pressure using the NMR technique. The data were analyzed statistically to determine relationships between the unfrozen water content and each of these variables. The effect of surcharge pressure was then compared with that predicted thermodynamically by various forms of the Clausius-Clapeyron equation.

MATERIALS AND METHODS

The soil used in this investigation was sampled from the vicinity of Manchester, N.H., and is designated Manchester or New Hampshire silt. The physical characteristics of the soil have been well defined, and numerous tests of its freezing behavior have been performed (Koopmans and Miller 1960, McGaw 1972, 1973). Six 200-g aliquots of dry soil were mixed with distilled water to form mixtures containing 0.10–0.225 g of H_2O per g of soil. The soil-water mixtures were sealed and allowed to equilibrate for one week. Following moisture equilibration, eight samples at each water content were compacted in three layers each in a 1.57-cm-diameter by 4.02-cm-high mold. The compaction hammer weighing 300.9 g had a free fall of 11.91 cm and exerted a compactive effort of 3.5×10^6 ergs per blow. Seventy-five blows were given to each sample. Following compaction, each sample was trimmed to 3.2 cm in length, and a hole 0.5 mm in diameter was drilled along its axis to accommodate a copper-constantan thermocouple. Each sample was inserted in a 1.68-cm-i.d. test tube and sealed with a rubber stopper to prevent moisture loss. The test tubes containing the compacted samples were placed in a temperature-regulated bath containing a mixture of ethylene glycol and water at a temperature of about +0.75°C.

The coolant in the bath was vigorously circulated with two submersible pumps, and the temperature was controlled with a Bayley proportional temperature controller.

A Praxis model PR-103 pulsed NMR analyzer was operated in the 90° mode with a 0.1-s clock and at a fast-scan speed. The first pulse amplitude in the 90° mode was measured for each sample starting at about +0.75°C. The test tubes were sequentially removed from the bath, wiped dry and inserted in the NMR analyzer. After about 4 s (the time required to record the sample temperature and the NMR pulse amplitude), the samples were reinserted in the bath. When all the samples were analyzed, the temperature was lowered about 0.2°C and the measurements were repeated. For each sample four readings above freezing were used to form a ratio between the NMR signal intensity and the sample water content.

Following the last observation at above-freezing temperatures, the test tubes containing the samples were placed in a coldroom at -20°C and allowed to freeze overnight. The next morning, circular lead weights, which were also cooled to -20°C, were inserted in the test tubes and brought to rest on two 1.25-cm-thick grooved Teflon disks that were placed on the soil (Fig. 1). The grooved disks ensured that

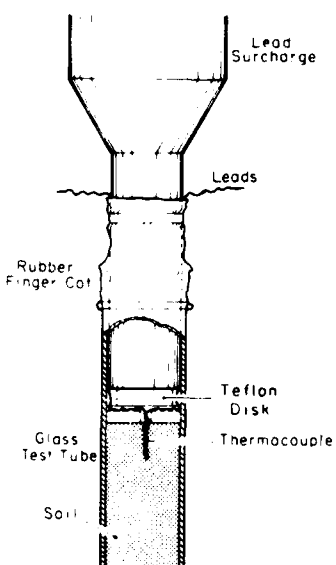

Figure 1. Schematic representation of a test tube containing a frozen soil plug with a lead weight surcharge.

the thermocouples did not interfere with the loading process and acted as thermal insulation between the soil and the weights. Six lead weights ranging from 75 g to 1600 g were added to six samples at each water content. Two samples at each water content were unweighted to provide a check on the reproducibility of the measurements. The unweighted samples and the two sets of samples with smaller weights were sealed with rubber stoppers to prevent moisture losses. The larger weights extended above the tops of the test tubes and were sealed with a thin, circular finger cot with the end cut off (Fig. 1).

The samples were removed from the coldroom and quickly placed in the temperature bath, preset to about -13.5°C. The top centimeter of the test tube and the larger weights extended above the top of the bath (Fig. 2), which caused two difficulties.

First, one set of weighted samples was ruined because moisture accumulated on the cold weights and then permeated into the soil. This problem was solved by installing a dehumidifier in the room and by blowing air over the samples with a large fan.

Second, the lead surcharge weights that extended above the bath cover conducted heat into the soil samples. This became apparent when the recorded temperatures for the samples with the heaviest weights exceeded 0°C and when the NMR data did not approach the value expected for a thawed sample. To determine the cause of this discrepancy, which was thought to be related to heat conduction through the lead weights, the following test was conducted. The temperature of the bath surrounding the samples was set at about 0°C, and the samples were allowed to reach thermal equilibrium. Temperature readings were taken on all samples. The weights were removed, and the depth of each thermocouple below the soil surface was measured. Depths ranged from 0.5 to 1.6 cm and averaged 1.04 cm. All the thermocouple holes were then redrilled to a depth of 2.7 cm, and the thermocouples were reinstalled. The 2.7-cm-depth corresponds to the limit of sensitivity of the NMR equipment. The weights were then reinserted, and the sample and weights were again allowed to reach thermal equilibrium. Temperatures were again recorded for all the samples, and this time the temperatures were within ±0.003°C, indicating that the temperature perturbation did not extend into the region of interest, that is, the region surrounded by the NMR detector coil. The temperatures were also within ±0.003°C of those measured near the top of the samples when the small weights were used. Therefore, when the data were analyzed, the temperatures of the samples containing the heaviest weights were changed to those recorded for unweighted samples immediately adjacent to them.

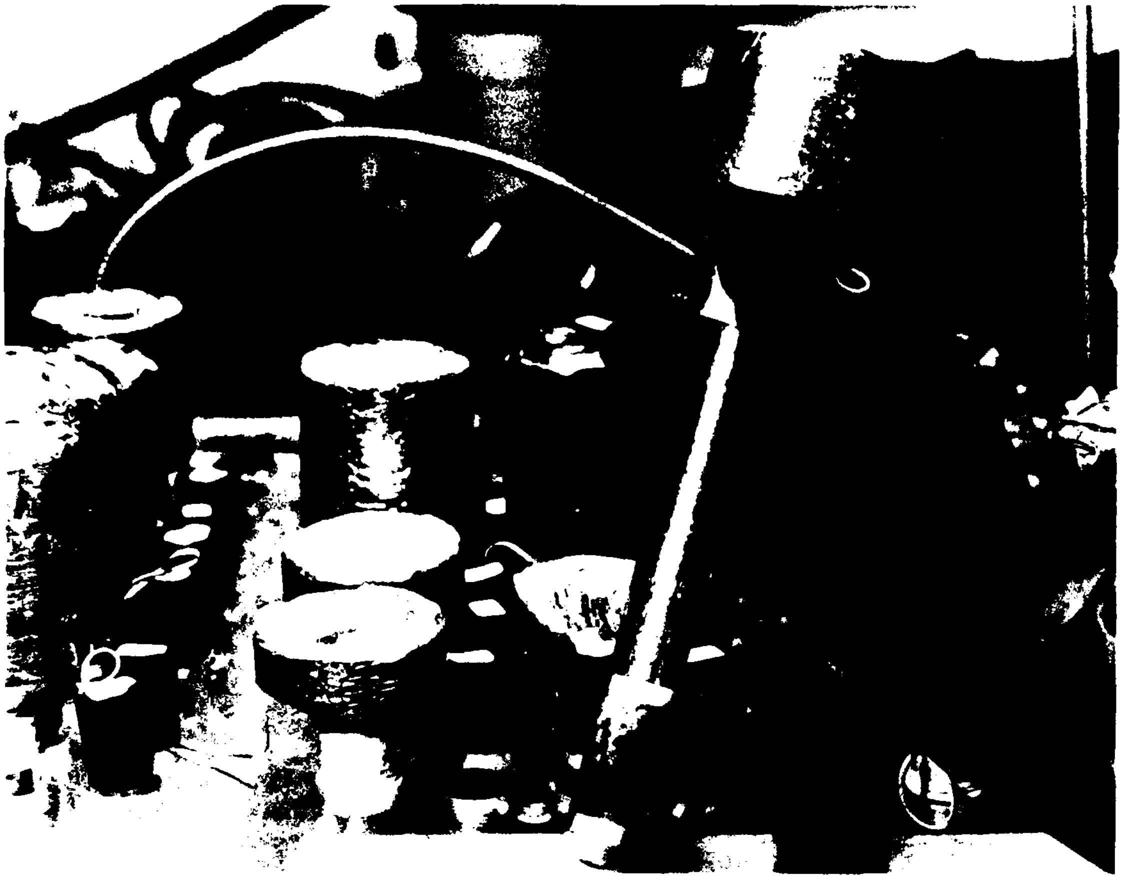

Figure 2. Weighted samples in the constant temperature bath.

Following temperature equilibration at -13.5°C, each sample, including its surcharge weight, was sequentially removed from the bath, wiped dry and inserted in the NMR detector. After about 4 s the samples were reinserted in the bath. When all the samples were analyzed, the bath temperature was changed and allowed to equilibrate. The process was repeated until data for complete phase composition curves were obtained. NMR signal intensities were measured on each sample at 18 temperatures between 0° and -13.5°C. There were eight samples at each water content (six weighted and two unweighted), and measurements were made at six water contents. This resulted in 144 readings at each water content and 864 for the entire experiment. After the final observations, water contents were determined gravimetrically, and a ratio of sample water content to thawed first pulse amplitude was developed. Unfrowater contents were calculated by multiplying first-pulse amplitudes by the respective ratios to obtain values of the unfrozen water content at each temperature (Tice et al. 1978). The unfrozen water content vs temperature data are listed in the Appendix for each water content and surcharge weight.

DATA ANALYSIS

According to the Clausius-Clapeyron equation (Edlefson and Anderson 1943, Williams 1964) if the surcharge on a frozen soil causes the pressure on the ice and water phases to increase by the same amount, then each kilogram-force per square centimeter of pressure will shift the unfrozen water content vs temperature curve by 0.0073 Celsius degrees. If the surcharge increases only the ice pressure while the water pressure remains constant, then the temperature drops by 0.088 Celsius degrees for each kilogram-force per square centimeter. In either case the effect of a surcharge is to shift the unfrozen water content vs temperature curve. In the following analysis, then,

any surcharge effect is assumed to have an equivalent temperature effect.

The surcharge effect on unfrozen water content was isolated by first finding an *empirical* equation that would reasonably describe the unfrozen water content vs temperature curve. The parameters in this equation were determined by using a nonlinear least-squares analysis of all the data from samples having the same total water content. In this initial analysis the differences in surcharge among the various samples were ignored. Then, wherever the independent variable temperature T occurred in the empirical equation, the combination of independent variables T and surcharge S were substituted in the form $T + KS$, where K is the constant that defines the temperature equivalence of the surcharge and has units of °C-cm²/kgf. (The values -0.0073 and -0.008°C-cm²/kgf from the Clausius-Clapeyron equation are K values.) The revised empirical equation was then fit to the data, again using the nonlinear least-squares analysis, this time including the effect of surcharge. In this way the experimental value for K could be determined. Also, it could be determined if including surcharge effects significantly improved the fit of the equation to the data, that is, if the effects of surcharge were significant.

An empirical equation used by Anderson and Tice (1972) to relate temperature and unfrozen water content is

$$W_u = \alpha\theta^{\beta} \tag{1}$$

where

W_u = unfrozen water content (in % of dry soil weight)

θ = temperature below freezing (°C)

α and β = empirically determined parameters.

Although this equation fits the general shape of W_u vs θ curves quite well, the poorest fit was at the highest unfrozen water contents (at temperatures slightly below 0°C) on the Manchester silt samples. Figures 3 and 4 illustrate this for a typical sample (20% total water content and no surcharge). In Figure 3 the data and the best-fit curve are shown. In Figure 4 the residuals (the differences between predicted and measured values of W_u) are shown as a function of temperature. The curve for eq 1 fits especially poorly in the region between 0°C and about -1°C.

The region from 0°C to -1°C is where the unfrozen water content changes the fastest. Therefore, this is the region where the unfrozen water content is most sensitive to any surcharge. The empirical equation

$$W_u = A + B\,[1 - \exp(C\theta)]/\theta \tag{2}$$

fits the data better than eq 1, especially at temperatures just below 0°C. In this equation, A, B and C are empirical constants. Equation 2 has the property that at $\theta = 0$, $W_u = A + B(-C)$.

The parameters in eq 2 were determined at each total water content by using all the data obtained

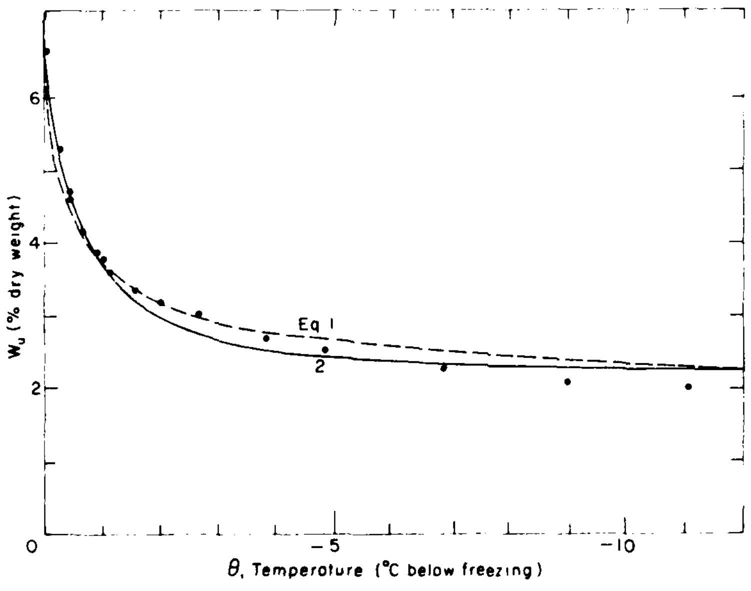

Figure 3. Unfrozen water content of a Manchester silt containing 20% of dry weight total water and with no surcharge.

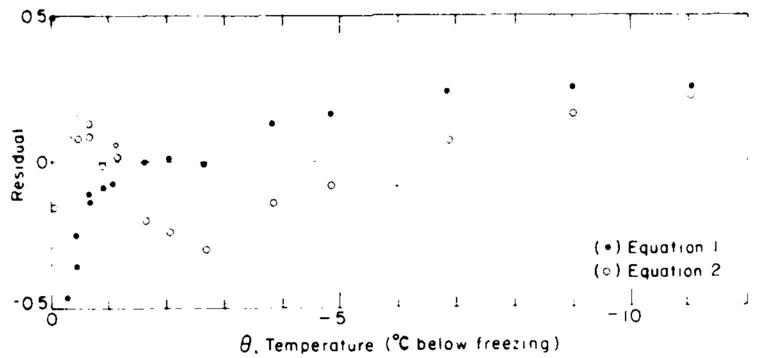

Figure 4. Residuals showing goodness of fit of eq 1 and eq 2 for the data shown in Figure 3.

from samples having that water content, regardless of surcharge. Then each set of data was used to find the parameters in the modified equation

$$W_u = A + B \left\{1 - \exp\left[C(\theta + KS)\right]\right\}/(\theta + KS) \quad (3)$$

taking into account the surcharge S. The values of A, B, C and K are listed in Table 1 for each set of samples. Also listed are the values for W_u when $\theta + KS = 0$. These values show no significant increase with increasing total water content, indicating that the amount of unfrozen water does not depend on the total amount of ice in the samples. The listed values of K show no discernible changes as a function of total water content. The six values have a mean of -0.297°C-cm²/kgf and a standard deviation of 0.048°C-cm²/kgf. The values for K that were found experimentally are considerably higher than those predicted using the Clausius-Clapeyron equation, i.e. -0.088 or -0.0073°C-cm²/kgf.

There are several ways to test the hypothesis that eq 3 fits the data significantly better than eq 2. This is equivalent to saying that surcharge has a significant effect on unfrozen water content. Because the values for K in Table 1 are relatively consistent and because zero is not within two standard deviations of the mean value of K, it is likely that the surcharge has a significant effect.

The sum of the squares of the residuals obtained when using eqs 2 or 3 as the model can be divided by the degrees of freedom attributable to the residuals (141 for eq 2 and 140 for eq 3) to obtain values of the residual mean square (Table 2).

A ratio of the residual mean square values can be formed to estimate the F statistic. At the 90% level of confidence, all six values for F show that eq 3 fits the data significantly better than eq 2 (Table 2). The F statistic is rather sensitive to the assumption that the populations being considered (in this case, the residuals) are normally distributed. Even though eq 2 fits the data better than eq 1, it is still not a "correct" model in that the residuals, as shown in Figure 4, are neither randomly nor normally distributed. Therefore, using the F statistic to compare dispersion is probably not valid.

Table 1. Parameters for eq 3.

Total water content (% of dry weight)	A *(% of dry weight)*	B *(°C × % of dry weight)*	C *(°C⁻¹)*	K *(°C-cm²/kgf)*	W_u *when θ + KS = 0 (% of dry weight)*
10	1.04	2.03	-2.33	-0.277	5.77
12.5	1.05	1.94	-2.45	-0.292	5.80
15	1.01	1.96	-2.34	-0.236	5.60
17.5	0.905	2.20	-2.11	-0.368	5.55
20	0.968	2.02	-2.36	-0.271	5.74
22.5	0.940	2.32	-2.18	-0.339	6.00

Table 2. Significance of surcharge effect.

Total water content (% of dry weight)	Surcharge in model	Residual mean square	F*	Z**
10	Yes	0.0945	1.41	1.52
	No	0.1333		
12.5	Yes	0.0904	1.52	1.15
	No	0.1377		
15	Yes	0.0618	1.39	2.00
	No	0.0861		
17.5	Yes	0.0898	1.68	2.23
	No	0.1512		
20	Yes	0.0748	1.47	2.09
	No	0.1103		
22.5	Yes	0.1098	1.58	0.810
	No	0.1735		

* If $F > 1.26$ the hypothesis that the variability or dispersion of the residuals is greater for the model when surcharge is not included can be accepted at the 90% confidence level.

** If $Z > 1.28$ the hypothesis that the variability or dispersion of the residuals is greater for the model when surcharge is not included can be accepted at the 90% confidence level.

The goodness of fit of eq 3 was compared to that of eq 2 by analyzing the residuals with the nonparametric Siegel-Tukey test for comparing dispersions (Siegel and Tukey 1960). The statistic Z, calculated at each total water content, is given in Table 2. For four of the values of total water content, eq 3 fits the data better than eq 2 at the 90% level of confidence. This claim cannot be made for the other two water contents.

We conclude that the experiments show a significant effect of surcharge and that the general magnitude of this effect is represented by the values of K given in Table 1.

DISCUSSION AND CONCLUSIONS

The average value for K in this study, $-0.297°C\text{-}cm^2/kg$, is 40 times greater than that predicted from the Clausius-Clapeyron equation with surcharge pressure increasing both ice and liquid phase pressures; it is 3.4 times greater than predicted for surcharge pressure increasing only ice phase pressure. Williams (1967) argued that any surcharge on a partially frozen soil will cause the pressure on both the ice and water phases to rise by the same amount at corresponding unfrozen water content values. This argument assumes that the system has reached thermodynamic equilibrium. In the experiments reported here the soil samples were frozen first, and then the surcharge was applied. Unfrozen water contents were measured at various temperatures as the samples were warmed in stages up to 0°C. Under the conditions of unconfined loading used, it is likely that equilibrium was not reached, but that the surcharge pressure was concentrated in the ice phase, causing the ice to migrate from areas of high stress concentration to areas of low stress concentration. Apparently, on the average, this migration was not completed during the time the experiment was being performed. If it is assumed that the surcharge pressure was concentrated by a factor of 3.4 into the ice phase, then the high effect of surcharge on the unfrozen water content can be explained.

The conditions used in this experiment correspond to conditions in the field where a surcharge load is placed on an already frozen soil. The unfrozen water content will be higher in the stressed region than what has been predicted by the Clausius-Clapeyron equation using unfrozen water content data on unloaded samples. This higher unfrozen water content would cause the ice to migrate away from the area of high stress faster than might otherwise be predicted.

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Appendix. Unfrozen water content and temperature data.

Total Water Content (% of dry weight)	Surcharge (g)	Temperature below 0°C	Unfrozen water content (% of dry weight)
10.025	622	13.55	0.896
		11.03	0.985
		8.98	1.101
		6.83	1.332
		4.83	1.622
		3.83	1.912
		2.65	2.202
		2.02	2.491
		1.63	2.549
		1.11	2.955
		1.03	3.303
		0.90	3.129
		0.69	3.534
		0.67	4.172
		0.46	4.867
		0.46	4.693
		0.28	5.041
		0.04	6.837
9.979	75	13.55	0.880
		11.03	0.997
		8.98	1.115
		6.83	1.232
		4.83	1.350
		3.83	1.643
		2.65	1.878
		2.02	2.054
		1.63	2.054
		1.11	2.465
		1.03	2.758
		0.90	2.582
		0.69	2.758
		0.67	3.228
		0.46	3.522
		0.46	3.463
		0.28	3.932
		0.04	5.048
9.863	370	13.55	0.928
		11.03	0.986
		8.98	1.160
		6.83	1.334
		4.83	1.566
		3.83	1.798
		2.65	2.088
		2.02	2.436
		1.63	2.842
		1.11	2.726
		1.03	3.248
		0.90	3.190
		0.69	3.655
		0.67	3.771
		0.46	4.177
		0.46	4.351
		0.28	5.047
		0.04	6.497
9.910	0	13.55	0.884
		11.03	1.002
		8.98	1.179
		6.83	1.415
		4.83	1.533
		3.83	1.769
		2.65	2.064
		2.02	2.418
		1.63	2.418
		1.11	2.536
		1.03	2.654
		0.90	2.654
		0.69	3.126
		0.67	3.480
		0.46	3.952
		0.46	3.716
		0.28	4.188
		0.04	5.603
9.661	1269	13.55	0.931
		11.03	0.989
		8.98	1.105
		6.83	1.396
		4.83	1.629
		3.83	1.862
		2.65	2.211
		2.02	2.502
		1.63	2.851
		1.11	2.968
		1.03	3.317
		0.90	3.317
		0.69	3.550
		0.67	3.899
		0.46	4.481
		0.46	4.481
		0.28	5.005
		0.04	7.274
9.743	0	13.55	0.927
		11.03	0.985
		8.98	1.101
		6.83	1.217
		4.83	1.565
		3.83	1.623

Total Water Content (% of dry weight)	Surcharge (g)	Temperature below 0°C	Unfrozen water content (% of dry weight)
		2.65	1.971
		2.02	2.203
		1.63	2.377
		1.11	2.493
		1.03	2.551
		0.90	2.667
		0.69	2.899
		0.67	3.131
		0.46	3.421
		0.46	3.653
		0.28	4.001
		0.04	5.625
9.552	1599	13.55	0.873
		11.03	0.990
		8.98	1.164
		6.83	1.281
		4.83	1.630
		3.83	1.805
		2.65	2.096
		2.02	2.388
		1.63	2.737
		1.11	3.028
		1.03	3.203
		0.90	3.319
		0.69	4.426
		0.67	3.960
		0.46	4.251
		0.46	4.310
		0.28	4.834
		0.04	6.465
9.533	153	13.55	0.941
		11.03	1.000
		8.98	1.235
		6.83	1.529
		4.83	1.765
		3.83	2.000
		2.65	2.236
		2.02	2.471
		1.63	2.530
		1.11	2.706
		1.03	2.942
		0.90	2.824
		0.69	3.295
		0.67	3.707
		0.46	4.236
		0.46	3.942
		0.28	4.531
		0.04	6.473
12.160	1269	13.55	0.860
		11.03	0.975
		8.98	1.147

Total Water Content (% of dry weight)	Surcharge (g)	Temperature below 0°C	Unfrozen water content (% of dry weight)
		6.83	1.376
		4.83	1.606
		3.83	1.835
		2.65	2.122
		2.02	2.523
		1.63	2.695
		1.11	2.573
		1.03	3.498
		0.90	3.04
		0.69	3.384
		0.67	3.900
		0.46	4.359
		0.46	4.129
		0.28	4.705
		0.04	7.112
12.071	622	13.55	0.854
		11.03	1.024
		8.98	1.915
		6.83	1.366
		4.83	1.651
		3.83	1.765
		2.65	2.106
		2.02	2.448
		1.63	2.676
		1.11	2.960
		1.03	2.903
		0.90	2.903
		0.69	3.757
		0.67	4.213
		0.46	4.498
		0.46	4.270
		0.28	4.725
		0.04	6.775
12.038	1599	13.55	0.926
		11.03	0.983
		8.98	1.099
		6.83	1.331
		4.83	1.504
		3.83	1.794
		2.65	2.257
		2.02	2.430
		1.63	2.604
		1.11	2.893
		1.03	3.935
		0.90	3.356
		0.69	3.704
		0.67	3.761
		0.46	4.167
		0.46	4.803
		0.28	5.324
		0.04	7.234

Total Water Content (% of dry weight)	Surcharge (g)	Temperature below 0°C	Unfrozen water content (% of dry weight)
12,099	75	13,55	0,864
		11,03	0,979
		8,98	1,094
		6,83	1,267
		4,83	1,497
		3,83	1,670
		2,65	2,016
		2,02	2,131
		1,63	2,189
		1,11	2,419
		1,03	2,880
		0,90	2,8231
		0,69	2,823
		0,67	2,880
		0,46	3,572
		0,46	3,687
		0,28	4,033
		0,04	5,415
12,113	0	13,55	0,918
		11,03	0,918
		8,98	1,090
		6,83	1,262
		4,83	1,435
		3,83	1,722
		2,65	2,009
		2,02	2,238
		1,63	2,468
		1,11	2,411
		1,03	2,812
		0,90	2,698
		0,69	2,812
		0,67	3,272
		0,46	3,731
		0,46	3,961
		0,28	4,190
		0,04	5,740
11,896	153	13,55	0,923
		11,03	0,981
		8,98	1,097
		6,83	1,328
		4,83	1,559
		3,83	1,847
		2,65	2,078
		2,02	2,252
		1,63	2,367
		1,11	2,598
		1,03	2,771
		0,90	2,714
		0,69	2,945
		0,67	3,118

Total Water Content (% of dry weight)	Surcharge (g)	Temperature below 0°C	Unfrozen water content (% of dry weight)
		0,46	3,926
		0,46	3,926
		0,28	4,331
		0,04	6,063
11,803	370	13,55	0,934
		11,03	0,993
		8,98	1,110
		6,83	1,285
		4,83	1,577
		3,83	1,752
		2,65	2,161
		2,02	2,395
		1,63	2,746
		1,11	2,979
		1,03	2,979
		0,90	3,330
		0,69	3,564
		0,67	3,797
		0,49	4,674
		0,46	4,791
		0,28	4,908
		0,04	7,011
11,781	0	13,55	0,933
		11,03	0,991
		8,98	1,049
		6,83	1,341
		4,83	1,574
		3,83	1,749
		2,65	2,157
		2,02	2,274
		1,63	2,332
		1,11	2,974
		1,03	2,799
		0,90	2,799
		0,69	3,207
		0,67	3,207
		0,46	3,440
		0,46	3,674
		0,28	4,024
		0,04	5,132
15,383	0	13,55	0,957
		11,03	0,957
		8,98	1,070
		6,83	1,352
		4,83	1,521
		3,83	1,690
		2,65	1,972
		2,02	2,197
		1,63	2,366
		1,11	2,479
		1,03	2,592

Total Water Content (% of dry weight)	Surcharge (g)	Temperature below 0°C	Unfrozen water content (% of dry weight)
		0,90	2,648
		0,69	2,761
		0,67	2,930
		0,46	3,493
		0,46	3,549
		0,28	4,057
		0,04	5,578
15,177	75	13,55	0,775
		11,03	0,886
		8,98	1,052
		6,83	1,218
		4,83	1,550
		3,83	1,606
		2,65	2,104
		2,02	2,104
		1,63	2,271
		1,11	2,492
		1,03	2,714
		0,90	2,769
		0,69	2,935
		0,67	3,157
		0,46	3,711
		0,46	3,766
		0,28	4,265
		0,04	5,594
15,183	0	13,55	0,856
		11,03	0,970
		8,98	1,084
		6,83	1,312
		4,83	1,484
		3,83	1,712
		2,65	1,997
		2,02	2,169
		1,63	2,226
		1,11	2,511
		1,03	2,625
		0,90	2,911
		0,69	2,796
		0,67	3,196
		0,46	3,767
		0,46	3,767
		0,28	4,223
		0,04	5,365
15,020	370	13,55	0,890
		11,03	1,056
		8,98	1,056
		6,83	1,279
		4,83	1,446
		3,83	1,724
		2,65	2,002
		2,02	2,280

Total Water Content (% of dry weight)	Surcharge (g)	Temperature below 0°C	Unfrozen water content (% of dry weight)
		1,63	2,336
		1,11	2,725
		1,03	2,892
		0,90	2,837
		0,69	3,115
		0,67	3,337
		0,46	3,894
		0,46	3,949
		0,28	4,672
		0,04	6,230
15,080	153	13,55	0,893
		11,03	1,005
		8,98	1,0611
		6,83	1,284
		4,83	1,508
		3,83	1,787
		2,65	2,066
		2,02	2,289
		1,63	2,513
		1,11	2,569
		1,03	2,960
		0,90	2,736
		0,69	2,904
		0,67	3,406
		0,46	3,853
		0,46	3,965
		0,28	4,300
		0,04	5,808
14,730	622	13,55	0,896
		11,03	0,952
		8,98	1,064
		6,83	1,232
		4,83	1,512
		3,83	1,792
		2,65	2,128
		2,02	2,352
		1,63	2,632
		1,11	2,800
		1,03	2,968
		0,90	2,856
		0,69	2,968
		0,67	3,528
		0,46	4,312
		0,46	4,536
		0,28	4,872
		0,04	6,384
14,570	1269	13,55	0,949
		11,03	1,060
		8,98	1,172
		6,83	1,395
		4,83	1,618

Total Water Content (% of dry weight)	Surcharge (g)	Temperature below 0°C	Unfrozen water content (% of dry weight)
		3.83	1.898
		2.65	2.232
		2.02	2.623
		1.63	2.902
		1.11	2.847
		1.03	3.181
		0.90	3.014
		0.69	3.628
		0.67	3.740
		0.46	4.075
		0.46	3.963
		0.28	4.800
		0.04	6.363
13.830	1599	13.55	0.800
		11.03	0.907
		8.98	1.014
		6.83	1.228
		4.83	1.548
		3.83	1.708
		2.65	2.135
		2.02	2.349
		1.63	2.669
		1.11	2.776
		1.03	3.043
		0.90	3.257
		0.69	3.791
		0.67	3.951
		0.46	4.432
		0.46	4.058
		0.28	5.660
		0.04	5.873
18.029	75	13.55	0.874
		11.03	0.983
		8.98	1.038
		6.83	1.201
		4.83	1.475
		3.83	1.639
		2.65	1.912
		2.02	2.239
		1.63	2.185
		1.11	2.513
		1.03	2.677
		0.90	2.677
		0.69	2.840
		0.67	3.223
		0.46	3.824
		0.46	4.042
		0.28	4.370
		0.04	5.463
17.868	370	13.55	0.874
		11.03	0.928

Total Water Content (% of dry weight)	Surcharge (g)	Temperature below 0°C	Unfrozen water content (% of dry weight)
		8.98	0.983
		6.83	1.256
		4.83	1.475
		3.83	1.584
		2.65	2.021
		2.02	2.349
		1.63	2.458
		1.11	2.677
		1.03	3.333
		0.90	3.169
		0.69	3.661
		0.67	3.824
		0.46	4.207
		0.46	4.480
		0.28	4.972
		0.04	6.611
17.721	1599	13.55	0.815
		11.03	0.924
		8.98	1.141
		6.83	1.250
		4.83	1.630
		3.83	1.793
		2.65	2.337
		2.02	2.609
		1.63	2.881
		1.11	3.098
		1.03	3.315
		0.90	3.370
		0.69	3.859
		0.67	3.968
		0.46	4.348
		0.46	4.403
		0.28	5.381
		0.04	6.740
17.738	622	13.55	0.878
		11.03	0.933
		8.98	1.098
		6.83	1.263
		4.83	1.482
		3.83	1.757
		2.65	2.031
		2.02	2.306
		1.63	2.690
		1.11	2.745
		1.03	2.800
		0.90	2.910
		0.69	2.910
		0.67	3.514
		0.46	4.173

Total Water Content (% of dry weight)	Surcharge (g)	Temperature below 0°C	Unfrozen water content (% of dry weight)
		0.69	2.849
		0.67	3.172
		0.46	3.728
		0.46	3.561
		0.28	3.951
		0.04	5.120
17.283	153	13.55	0.828
		11.03	0.883
		8.98	0.993
		6.83	1.214
		4.83	1.435
		3.83	1.711
		2.65	1.932
		2.02	2.208
		1.63	2.374
		1.11	2.484
		1.03	2.650
		0.90	3.036
		0.69	3.069
		0.67	3.368
		0.46	4.030
		0.46	4.196
		0.28	4.196
		0.04	5.908
19.801	153	13.55	0.858
		11.05	0.912
		8.98	1.073
		6.83	1.287
		4.83	1.556
		3.83	1.824
		2.65	2.039
		2.02	2.414
		1.63	2.468
		1.11	2.575
		1.03	3.005
		0.90	2.987
		0.69	3.166
		0.67	3.166
		0.46	3.595
		0.46	3.809
		0.28	4.400
		0.04	6.385
19.672	622	13.55	0.812
		11.03	0.975
		8.98	1.083
		6.83	1.246
		4.83	1.517
		3.83	1.734
		2.65	2.059
		2.02	2.330
		1.63	2.492

Total Water Content (% of dry weight)	Surcharge (g)	Temperature below 0°C	Unfrozen water content (% of dry weight)
		0.46	4.887
		0.28	5.326
		0.04	6.864
17.609	0	13.55	0.822
		11.03	0.877
		8.98	0.987
		6.83	1.206
		4.83	1.481
		3.83	1.590
		2.65	1.919
		2.02	2.194
		1.63	2.139
		1.11	2.503
		1.03	2.523
		0.90	2.578
		0.69	2.742
		0.67	2.962
		0.46	3.455
		0.46	3.510
		0.28	3.839
		0.04	5.321
17.393	1269	13.55	0.869
		11.05	0.978
		8.98	1.087
		6.83	1.358
		4.83	1.576
		3.83	1.793
		2.65	2.119
		2.02	2.717
		1.63	2.880
		1.11	3.043
		1.03	2.532
		0.90	3.532
		0.69	4.728
		0.67	4.402
		0.46	4.728
		0.46	4.348
		0.28	4.946
		0.04	6.631
17.309	0	13.55	0.779
		11.03	0.946
		8.98	1.001
		6.83	1.168
		4.83	1.502
		3.83	1.614
		2.65	1.947
		2.02	2.114
		1.63	2.337
		1.11	2.360
		1.03	2.615
		0.90	2.727

Total Water Content (% of dry weight)	Surcharge (g)	Temperature below 0°C	Unfrozen water content (% of dry weight)
		1.11	2.818
		1.03	3.034
		0.90	2.980
		0.69	3.197
		0.67	3.576
		0.46	4.498
		0.46	4.389
		0.28	4.660
		0.04	6.828
19.842	740	13.55	0.865
		11.03	0.919
		8.98	1.081
		6.83	1.243
		4.83	1.459
		3.83	1.676
		2.65	2.108
		2.02	2.324
		1.63	2.703
		1.11	3.027
		1.03	3.243
		0.90	3.243
		0.69	3.622
		0.67	3.676
		0.46	4.217
		0.46	4.163
		0.28	4.595
		0.04	6.217
19.855	1599	13.55	0.800
		11.03	0.907
		8.98	1.014
		6.83	1.227
		4.83	1.547
		3.83	1.654
		2.65	2.134
		2.02	2.508
		1.63	2.615
		1.11	3.095
		1.03	3.149
		0.90	3.362
		0.69	3.629
		0.67	3.736
		0.46	4.269
		0.46	4.696
		0.28	4.963
		0.04	6.458
19.829	1269	13.55	0.848
		11.05	0.901
		8.98	1.007
		6.83	1.272
		4.83	1.590

Total Water Content (% of dry weight)	Surcharge (g)	Temperature below 0°C	Unfrozen water content (% of dry weight)
		3.83	1.802
		2.65	2.067
		2.02	2.385
		1.63	2.703
		1.11	2.650
		1.03	3.022
		0.90	3.181
		0.69	4.559
		0.67	3.976
		0.46	3.817
		0.46	4.559
		0.28	4.983
		0.04	7.157
19.795	75	13.55	0.800
		11.03	0.907
		8.98	0.960
		6.83	1.173
		4.83	1.440
		3.83	1.547
		2.65	1.867
		2.02	2.134
		1.63	2.294
		1.11	2.347
		1.03	2.561
		0.90	2.667
		0.69	3.041
		0.67	3.094
		0.46	3.628
		0.46	3.681
		0.28	4.055
		0.04	5.068
19.781	0	13.55	0.804
		11.03	0.911
		8.98	1.018
		6.83	1.232
		4.83	1.393
		3.83	1.608
		2.65	1.876
		2.02	2.197
		1.63	2.144
		1.11	2.251
		1.03	2.51[illegible]
		0.90	2.787
		0.69	2.948
		0.67	3.109
		0.46	3.538
		0.46	3.806
		0.28	4.181
		0.04	5.575

Total Water Content (% of dry weight)	Surcharge (g)	Temperature below 0°C	Unfrozen water content (% of dry weight)
19.636	0	13.55	0.932
		11.03	0.932
		8.98	1.042
		6.83	1.206
		4.83	1.480
		3.83	1.645
		2.65	2.029
		2.02	2.193
		1.63	2.358
		1.11	2.577
		1.03	2.797
		0.90	2.907
		0.69	3.181
		0.67	3.181
		0.46	3.674
		0.46	3.784
		0.28	4.387
		0.04	5.814
21.115	622	13.55	0.915
		11.03	0.915
		8.98	1.077
		6.83	1.238
		4.83	1.562
		3.83	1.777
		2.65	2.100
		2.02	2.477
		1.63	2.531
		1.11	3.178
		1.03	3.178
		0.90	3.716
		0.69	4.416
		0.67	3.770
		0.46	4.901
		0.46	4.093
		0.28	4.740
		0.04	6.086
21.347	153	13.55	0.821
		11.03	0.985
		8.98	1.094
		6.83	1.258
		4.83	1.587
		3.83	1.806
		2.65	2.134
		2.02	2.408
		1.63	2.517
		1.11	2.517
		1.03	3.119
		0.90	2.846
		0.69	3.174
		0.67	3.722

Total Water Content (% of dry weight)	Surcharge (g)	Temperature below 0°C	Unfrozen water content (% of dry weight)
		0.46	4.105
		0.46	4.324
		0.28	5.254
		0.04	6.294
21.100	1269	13.55	0.795
		11.03	0.954
		8.98	1.060
		6.83	1.325
		4.83	1.590
		3.83	1.749
		2.65	2.279
		2.02	2.703
		1.63	2.915
		1.11	2.915
		1.03	3.552
		0.90	3.552
		0.69	3.498
		0.67	4.241
		0.46	4.612
		0.46	4.771
		0.28	5.195
		0.04	8.641
21.045	0	13.55	0.813
		11.03	0.813
		8.98	0.976
		6.83	1.139
		4.83	1.410
		3.83	1.735
		2.65	1.952
		2.02	2.278
		1.63	2.278
		1.11	2.440
		1.03	2.766
		0.90	2.874
		0.69	3.037
		0.67	3.308
		0.46	3.417
		0.46	3.634
		0.28	4.71
		0.04	5.369
21.092	75	13.55	0.809
		11.03	0.970
		8.98	1.024
		6.83	1.294
		4.83	1.564
		3.83	2.157
		2.65	2.643
		2.02	3.182
		1.63	2.912
		1.11	2.697
		1.03	3.236

Total Water Content (% of dry weight)	Surcharge (g)	Temperature below 0°C	Unfrozen water content (% of dry weight)
		0.90	3.452
		0.69	3.668
		0.67	4.153
		0.46	4.531
		0.46	4.423
		0.28	4.962
		0.04	6.041
21.031	1599	13.55	0.808
		11.03	0.916
		8.98	0.970
		6.83	1.186
		4.83	1.509
		3.83	1.779
		2.65	2.264
		2.02	2.426
		1.63	2.588
		1.11	2.804
		1.03	3.666
		0.90	3.936
		0.69	3.936
		0.67	4.206
		0.46	5.230
		0.46	5.176
		0.28	5.338
		0.04	7.441
20.871	370	13.55	0.823
		11.03	0.933
		8.98	1.043
		6.83	1.208
		4.83	1.428
		3.83	1.702
		2.65	2.032
		2.02	2.416
		1.63	2.746
		1.11	2.965
		1.03	3.020
		0.90	3.185
		0.69	3.515
		0.67	3.954
		0.46	4.613
		0.46	4.338
		0.28	4.778
		0.04	6.353
20.690	0	13.55	0.818
		11.03	0.928
		8.98	1.037
		6.83	1.146
		4.83	1.473
		3.83	1.692
		2.65	2.074

Total Water Content (% of dry weight)	Surcharge (g)	Temperature below 0°C	Unfrozen water content (% of dry weight)
		2.02	2.347
		1.63	2.238
		1.11	2.620
		1.03	2.729
		0.90	2.893
		0.69	3.057
		0.67	3.275
		0.46	3.875
		0.46	3.821
		0.28	4.476
		0.04	6.005

END

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